Using the Research-Based Standards To Help Students Learn

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Introduction

Many students experience trouble with at least some concepts in a high school chemistry course. Students often explain their difficulty as a consequence of either not being "good" at math or science. Sometimes students place the blame on the teacher as someone who knows the science, but is not skillful at teaching. Whatever the problem, the thought of taking a chemistry course can cause a good deal of anxiety in many students. So why is chemistry perceived by some students as being so difficult? Is the subject inherently complex and accessible to only the top academic tier of students? If this is true, then why do the *National Science Education Standards* (NSES) include understanding of chemistry and chemistry-based principles as necessary for a quality education? Research suggests several reasons why

chemistry is perceived as difficult, including the mismatch that can occur between the way chemistry is taught and how students learn. It is our premise, and that of other researchers, that chemistry is something that all students can learn if it is taught in a way that is aligned with how the brain operates. This chapter will explore some current ideas in the research of learning and teaching and then attempt to integrate this research with the NSES. We also offer some practical teaching examples keyed to the pertinent NSES to facilitate student learning.

Research in Learning

Researchers' analyses of teaching and learning methodologies have identified several basic principles involved in the teaching and understanding of subjects such as chemistry. Included in their findings are the following observations:

- In order for new knowledge to be learned, it must be integrated with what the learner already knows. This means that it is crucial that both the student and teacher ascertain what the student knows about a topic before new information is presented (Novak and Gowin, 1984).
- There is a difference between truly understanding the subject matter and simply being able to pass a course. This difference can be highlighted by asking students to apply what they know to novel situations rather than using problems that are parallel to what has been shown in class (Novak and Gowin, 1984).
- Students must be actively engaged in the learning process. They cannot be passive recipients of knowledge. It is essential that they are involved in the process of integrating new knowledge with the knowledge they already have (Bodner and Klobuchar, 2001; Nurrrenbern, 2001). One way to actively involve students is to engage them in group work where answers to problems are debated and agreed upon by a group of peers (Johnson, Johnson, and Smith, 1998).


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- Students need time and opportunities to *interpret* chemical concepts in their own work, *practice* applying these concepts to new situations, and *reflect and modify* their understanding of chemical concepts (Karplus, 1980).
- In order for students to be able to reliably learn new concepts, they must be aware of the process in which they are engaged when they integrate new information (Flavell, 1979). This self-awareness, known as *metacognition*, will aid in the process of learning a specific concept and help in understanding future related concepts.
- Chemistry is one of the first courses students encounter in science that has a large number of abstract concepts. Students can see muscles and bones in biology, and minerals and rocks in geology, but atoms, ions, and molecules are not visible to the naked eye. Molecular interactions are central to understanding chemistry. This move from concrete, observable phenomena to abstract, unseen molecular interactions is not always easy for students at different levels of cognitive maturity (Nurrrenbern, 2001).
- Chemists move seamlessly among the macroscopic (large-scale phenomena), particulate (interactions of atoms, ions, and molecules), and symbolic (chemical formulas and mathematical equations) levels. Unless students are explicitly taught to link these three views of matter and move back and forth among them, they will not be able to understand chemical concepts the way chemists do (Johnstone, 1997). (See chapter 14 for a more detailed discussion of Johnstone's levels.)
- The short-term memory of the brain has a limited capacity and can easily be overwhelmed by new concepts explained with a new vocabulary and using unfamiliar equipment and techniques (Simon, 1979).

Research in Teaching

Research has also elucidated several aspects of teaching that can be used to help students learn effectively, including the following:

- "One size" teaching does not fit all students. There are students, who either because of their previous knowledge or their preferred mode of learning, will learn most effectively from a lecture format. However, these students are few and far between. Even if lecture is the preferred mode of learning for students, it may not be effective at times in the student's life when there are competing events for the student's attention. The teacher can help all students by presenting different topics in different formats and/or making alternative formats available to students (Campbell et al., 2001). These alternative formats may include animations on the Web, lab experiments, demonstrations, small group work, research papers, free response answers that require logical arguments, structured notes, diagrams, and model kits.
- The role of a teacher has changed from the "keeper of the knowledge" to the "designer of a learning environment" where the student can operate successfully. This idea of the teacher as a designer of the learning environment is a role that is deeply imprinted on the human psyche. Parents of toddlers (humans new to the concepts of life) baby-proof their homes so that the children do not hurt themselves. They also create learning opportunities that match the abilities of the child and enable the child to master and then grow into new applications of skills by providing age-appropriate toys, tasks, books, CD/DVDs and other learning materials. The teacher's role as a learning environment designer is similar. The teacher cannot learn the chemistry for the student. However, the teacher can construct the activities and materials that will allow students to confront, practice, reflect, and modify their learning experiences (Karplus, 1980).
- If students operate in a learning environment where their egos are protected from undue stress, their naïve ideas listened to and gently critiqued with new directions provided, students, like all human beings, will have a better chance to grow in their understanding (Novak and Gowin, 1984).
- Students need assessments that truly help their understanding. Tests and other forms of student work should not be viewed as barriers to be overcome. Rather they should be considered signposts to help direct student learning. This doesn't mean that students should not be given a grade for accomplishing the task of understanding, but rather that the assessment should be well focused and seen as a learning opportunity in and of itself (Fuchs and Fuchs, 1986).

Learning Research Goals and the *National Science Education Standards*

Many of the research results on learning and teaching are reflected in the NSES. It is the goal of this chapter to offer suggestions on how to implement the results of research on learning and teaching, as incorporated into the NSES to plausible and effective activities within the classroom. In keeping with this goal and as a result of discussions of problems, we have encountered in our own classrooms, we will address four basic research-based learning and teaching goals:

- Engage students and encourage them to take responsibility for their own learning
- Provide students with a voice in their own learning
- Approach the learner as an individual
- Apply chemistry concepts to the real world

Each of these goals will be discussed in terms of the relevant learning/teaching theory, connections to the relevant NSES, practical classroom approaches to addressing the goals/standards, and the enhanced delivery of these approaches through the use of technology. Table 1 presents an overview of this approach.

Additional resources are available to teachers who wish to address the NSES but are unsure how to approach this daunting task. Textbooks such as the *World of Chemistry* (Zumdahl, Zumdahl, and DeCoste, 2006) and others include references to the standards in their supplemental materials.

Table 1. Overview of Learning Research Goals and the NSES

Goal	Theory	NSES	Classroom Approach	Technology
Engage students/ Encourage responsibility for their learning	• Constructivism • Cooperative learning • Learning cycle	Teaching Standards A, B, D	• Cooperative learning groups • POGIL	• Interactive Web resources • Student response systems (Clickers) • ConcepTests
Provide students with a voice in their learning	• Metacognition • Reflective learning	Teaching Standards B, D, E	• Formative evaluations • Surveys • Class boards	• Class Web site • Clickers
Learner as an individual	• Learning styles • Piaget • Previous knowledge (Ausubel)	Teaching Standard B	• ConcepTests • Surveys • Formative evaluation	• Clickers • Class Web site • Interactive computer testing • Computer animations
Apply chemistry to real world	• Learning cycle • Three views of matter • Meaningful vs. rote learning (Ausubel)	Content Standard G	• Inquiry laboratory experiments • Web site or literature research of current topics	• Web sites • Computer searching of literature

***POGIL, Process Oriented Guided Inquiry Learning.**

The third column of Table 1 connects these learning research goals to specific standards. The NSES Teaching Standards are structured so that teachers can select, adapt, and design content that emphasize inquiry learning for students (Teaching Standard A). Teachers should function as facilitators of learning by designing opportunities for student discourse about science and by encouraging students to take responsibility for their own learning (Teaching Standard B). Learning science requires tools, materials, media, and technology for students to engage in hands-on exploration; teachers are the architects of designing these learning environments (Teaching Standard D). Teachers should develop communities of learners to reflect the values and processes of inquiry (Teaching Standard E) and engage students and encourage them to take responsibility for their own learning.

Engage Students and Encourage Them To Take Responsibility for Their Own Learning

Theory. When students are part of a cooperative group, the group itself encourages each member to contribute his or her part. Membership in a group implies joint responsibilities, as well as joint benefits. Attendance in class can improve if each group member has a specific role to play in the cooperative group such as leader, facilitator, reporter, or presenter. The group itself is diminished if a member is not present and someone else must assume the responsibility of the absent member. This scenario often prompts the group to apply pressure on its members

to be present in class and to fulfill their responsibilities to the group. As a group member, each student is an integral part of the learning experience and not just a faceless member of the larger class. Learning takes place through the group's discourse. Usually, this discourse goes through several stages from checking the parameters of the problem to making sure that the solution is logical (Daubenmire, 2004).

Students must construct their own knowledge as opposed to being passive recipients of the teacher's information. Students should be provided an opportunity to develop a concept, apply it, reflect on it, and modify it.

Corresponding National Science Standards (Center for Science, 1996) (Table 1)

Teaching Standard A

Teachers of science plan an inquiry-based science program for their students. In doing this, teachers

- Select science content and adapt and design curricula to meet the interests, knowledge, understanding, abilities, and experiences of students.

Teaching Standard B

Teachers of science guide and facilitate learning. In doing this, teachers

- focus and support inquiries while interacting with students,
- orchestrate discourse among students about scientific ideas, and
- challenge students to accept and share responsibility for their own learning.

Teaching Standard D

Teachers of science design and manage learning environments that provide students with the time, space, and resources needed for learning science. In doing this, teachers

- make the available science tools, materials, media, and technological resources accessible to students and
- identify and use resources outside the school.

Classroom application—Cooperative learning. When Advanced Placement chemistry classes are taught using guided inquiry techniques, students can become much more independent learners. One way to use guided inquiry is through use of Process-Oriented Guided Inquiry Learning (POGIL) curricula materials (POGIL, 2007). For instance, in the POGIL Activities for General Chemistry (Moog and Farrell, 2006), students move from critical thinking questions about the information that supports the electron shell model of atomic structure to exercises (application questions) and problems (extension questions) using that model. Learning takes place as students work in small groups and discuss and debate the answers and the reasons for them with each other. Students learn to rely on the group to interpret the material before asking the instructor for help with questions that they don't immediately understand. The basis of group assignment differs among teachers but can include mixed ability groups (one high ability, one low ability, and two middle ability students) or single ability (four high ability or four low ability students). Some teachers find that putting the lowest-ability students together in a group forces them to draw on their own knowledge and not depend on the "smart" kids for the answers. (Chapter 4 discusses POGIL in detail.)

Cooperative learning can also be accomplished by using other published cooperative learning activities such as Team Learning Sheets (Zumdahl, Zumdahl, and DeCoste, 2002*b*). These sheets are designed to be used in class to encourage active learning. In the laboratory, cooperative learning groups can use Report Sheets (Zumdahl, Zumdahl, and DeCoste, 2002*a*) to gather and analyze data. For example, an inquiry lab on solubilities can help clarify the idea of insoluble versus soluble ionic compounds. Students are given a number of unknowns and asked to plan their strategy before attempting to identify the unknowns through measurement of conductivity, pH, reactivity, and solubility, as different unknowns are mixed together (Zumdahl et al., 2002*a*).

Classroom application—Use of alternative or supplemental materials. Providing students with an outline of the topics that will be discussed in class and pertinent concepts that can be expanded during the discussion along with space to work out examples can help students stay engaged and take responsibility for their own learning. Projecting an outline of what will be covered in class, while class notes are discussed and elaborated, enables the teacher to face the class and engage students more directly. Problems can be worked out with the class as a whole, in small groups, or as individual assignments. The results are then discussed, projected, and added to the notes' outline.

Alternative approaches to engaging the learner include interactive demonstrations and simulations. One such simulation deals with the underlying principle of Rutherford's experiment. In this simulation, an unknown geometric shape is determined through an analysis of the path marbles take (angles of deflection) when passed under a board that obscures the identity of the geometric shape (triangle, pentagon, circle, etc.) (Zumdahl et al., 2002*a*). Just as Rutherford could not see the atom, students cannot see the geometric shape. Rolling marbles under the board and observing the deflection patterns allow the students to predict the shape, which is analogous to the procedure Rutherford used to hypothesize about the atom. This simulation helps to engage students in the learning process and shows them how discoveries can be made on the basis of logical analysis of appropriate data, even though a phenomenon cannot be viewed directly.


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Supplemental information for concepts can be listed on a teacher's Web page or course Web site. Another way to introduce supplemental material into the learning environment is through appropriate posters and other visual information in the classroom. For instance, a good way to start a discussion of the mole is with the *ChemMatters* poster (Soule, Schwartz, and Pryde, 1985) that illustrates a mole each of marbles, pennies, and moles (animals), as well as other examples. This visual representation of an abstract concept helps students comprehend the size of a mole.

Supplemental information for lab experiences can include online simulated lab activities that reinforce specific concepts or lab procedures.

Technology. Class Web sites that provide students with alternative or supplemental resources can help empower them to take responsibility for their own learning. Computer files or URL's supporting concepts taught in class can be an effective way to both engage students and help them become responsible for their own learning.

Class Web sites also provide the ability to post class messages when necessary. An example is communication during inclement weather when it is important not to lose the learning opportunity interfered with by the weather by letting students know what they should be working on. As high schools become more Web-oriented, many additional files can be posted for the students' benefit, including answer keys to worksheets, students' grades (with individual password-protected access), discussion groups, assignments, writing guidelines for lab reports, and course syllabus. Students will then be better able to take charge of their learning. (See chapter 7 for a detailed discussion of how technology can improve student learning in chemistry.)

Provide Students With a Voice in Their Own Learning

Theory. Students and teachers are both stakeholders in the learning outcomes of the classroom. Since both are involved in the process, both should have input. This input does not

necessarily mean that the teacher and students are equal partners in determining what will be taught or how much content will be covered in a school year. But by listening to students, teachers can better understand whether the approach they are using is meeting their students' needs. Students can learn that there is a difference between "whining" and actively engaging in a constructive discussion of what is or is not working in their quest for true understanding. If students share the responsibility for the learning environment, they are more likely to share responsibility for their own learning.

Corresponding National Science Standards (Table 1)

Teaching Standard B, D, and E

- Teachers of science develop communities of science learners that reflect the intellectual rigor of scientific inquiry and the attitudes and social values conducive to science learning.
- Students are enabled to have a significant voice in decisions about the content and context of their work and require students to take responsibility for the learning of all members of the community.

Classroom application—Learning from their mistakes. One approach to helping students take responsibility for their learning is to provide students with time either in or outside class to discuss their errors and write corrections with reflections on how to avoid making the same mistakes in the future. This activity helps students internalize the concept and develop a strategy for avoiding repeated mistakes. Students can submit their corrections for credit.

Students are given some choice in terms of alternative evaluations. A science fair project/class presentation or a fourth-quarter research paper/class presentations are options students might choose in place of a test.

Classroom application—Evaluation. Lab reports can be used as a means to evaluate more than a specific laboratory experiment's results. The conclusion section of a lab report can include both conclusions based on data and an evaluation of the lab. Such evaluations can contain answers to questions such as what worked, what didn't, was the lab objective achieved, and what was learned by doing the lab. If the student misses the intent of the lab, as evidenced by the answers to these questions, then the teacher can help guide the student to an understanding of the lab's purpose.

Students can take an active role in designing their learning environment by completing course evaluations throughout the course. The evaluations can include questions related to length of assignments, pace of course, use of lab work, and supplemental materials (videos, worksheets, etc.). Instead of learning that students don't understand a concept on a test or quiz, a regular process for determining how effective specific teaching approaches have been and possible recommendations for how to improve them is provided. More frequent evaluation or input from students enables teachers to change or modify their methods of teaching, while the course is still in progress.

Classroom application—Class boards. To encourage meaningful discussion between the members of the class and the teacher on issues of student learning, class boards can be set up. Elected student representatives to the board meet with the teacher on a regular basis (weekly or monthly) to discuss issues that are of importance to members of the class. Minutes of the meeting, including responses to the concerns raised, are posted on the course Web site and made available to all students in the class.

Technology. Class Web sites can be used to host online discussions (either in real time or in threaded discussion boards) where students and teachers discuss elements of the course that are

of mutual concern. Class Web sites can also be used to post minutes from Class board meetings so that they can be easily accessed by all members of the class. Student response systems (Clickers) can be used for short, informal surveys of important, time-sensitive issues such as rescheduling a test due to an unexpected snow day.

Approaching the Learner as an Individual

Theory. Contrary to the typical reference of teaching a class, teachers do not actually teach a "class." We teach individual students. These students are at different stages of psychological development, academic and social maturity, attention level, assimilation into American society, emotional states, or have preferred approaches to learning (visual, verbal, or kinesthetic). All of these differences cannot possibly be addressed in each teaching activity, but teachers can provide alternative approaches to learning concepts, including those that focus on visual, oral, or kinesthetic approaches. Teachers can help teach students how to be focused and persevere in their studies when their lives are in turmoil—whether real or imagined. To do this, the learning activities should be designed to focus on the students and engage them in an interactive experience of the concepts whether through simulation, demonstration, laboratory, guided activity, collaborative groups, or problem solving. Only then do teachers have a chance to effectively reach a diverse audience. Students should be engaged in activities that make them aware of how much they understand a concept and what they still need to work on. This metacognitive process involves student reflection on the state of their knowledge and an assessment of what they know and what they need to know. When students become aware of their own internal cognitive processes, they can more closely monitor the progress of their learning and eventually become a more active participant in their learning.

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Corresponding National Science Standards (Table 1)

Teaching Standard B

Teachers of science guide and facilitate learning. In doing this, teachers

- challenge students to accept and share responsibility for their own learning and
- recognize and respond to student diversity and encourage all students to participate fully in science learning.

Classroom application—Assignment of groups. Group activities can help students of different cultures more easily become incorporated into the class by acknowledging their contributions within a smaller group. It is important not to isolate a shy member of a minority group by placing him or her alone in a group that will not automatically solicit the student's input. Assigning two students of the same culture to a group of four provides a certain amount of support for all students. Groups can be changed on a regular basis to help each student learn to work with others and not become dependent on certain individuals in the original group. Group assignment is not the only thing to consider in this situation. It is important for the teacher to encourage full participation by all members of the cooperative group.

Classroom application—Addressing different learning preferences. A variety of teaching methods can be used to reach the auditory learner, the visual learner, and the student that is learning disabled (LD). The use of class notes that are expanded as the class discussion

proceeds helps all three types of learners. This technique has also been used to aid learners who have been identified by professionals as needing a "note-taking buddy". In expandable notes, a basic outline of what will be covered is given to each student. As the class progresses through a discussion of the material, examples are added utilizing a conventional or tablet-type computer and LCD projector. Students can then add these examples to their outline. The example is discussed, and the students annotate their notes. The notes and examples are then saved on the computer and made available to students who were absent for that presentation or anyone else who wishes to check the quality of their notes against those of the teacher. Teachers are able to facilitate improved class participation and be more aware when a student seems confused or frustrated. In such a case, the student can be helped individually by the teacher at an appropriate time. Teachers can also help students focus more effectively on the concept being discussed through the class interaction.

Classroom application—Labs. Lab experiments allow students to view and manipulate on the macroscopic level what they have only read or learned about in class. Small groups of two or three provide an opportunity for all students to have a hands-on experience with a new concept. The ability to link the macroscopic with the symbolic view of chemistry is a major step forward in understanding. Once students are comfortable moving between these two views of matter, using a third view, particulate, to explain chemical phenomenon will likely be easier for them to grasp.

Technology. Use of Web pages as a repository for supplemental resources that are more visual than those used in class or as a file manager for class notes enables students to access the resources they need to help support their learning preferences or to supplement their understanding. Using technology in the classroom whether it is a tablet-style computer that supports free-form writing or computer-LCD projector combination as a way to both project the current information and to retain an electronic record, helps students who require additional support in the learning process.

Applying Chemistry to the Real World

Theory. In order for meaningful learning to take place, the student must integrate the newly acquired knowledge with that he or she currently possesses. If the new knowledge deals only with issues that the student encounters within school and appears to have little or no connection with the real world, there is a risk that the school knowledge, even if it is learned, will be held in isolation from real-world knowledge. This parallel processing of knowledge will make it difficult for the student to apply science concepts outside of a school setting, thus limiting the impact those scientific concepts have on the student's understanding of the world.

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Corresponding National Science Standards (Table 1)

Content Standard G

As a result of activities in grades 9–12, all students should develop an understanding of

- science as a human endeavor and
- the nature of scientific knowledge.

Classroom Application–Connecting life situations with chemistry concepts. What better way to capture students' attention than by talking about food? Food is a natural blend of real-world concerns and chemistry. Physical and chemical changes can be illustrated

by calling upon the students' own experiences with food, including what happens to food left too long on the counter versus the refrigerator. Gas laws can be introduced with the opening of warm and cold soda bottles. Acid-base reactions can be addressed through the need for antacid tablets after a large meal. Even a discussion of pH can begin with the pool testing kits used by home or community pool lifeguards. This discussion can be expanded to include students' knowledge of aquarium pH balance or the advantages of using a pH-balanced shampoo. Limiting reagents can be addressed through the effect of running out of specific ingredients while cooking. Once students are hooked on the real-world topic, it is easier to direct their interest in the underlying chemical concepts.

The application of chemical concepts to real-world phenomena can be further investigated through research papers or written assignments. Use of Web-based search engines to locate print and electronic information is a worthwhile skill for students to develop while they are learning chemistry. LexisNexis (Elsevier, 2006) and EBSCO (Ebsco, 2007) are two search engines that many students are already familiar with. This Web-searching skill can be tapped to help locate sound scientific knowledge about real-world topics.

Technology. Using the Web as a source of information to link chemistry concepts with real-world phenomena is an effective way to research the underlying chemical concepts for phenomena outside the chemistry classroom. Learning how to locate information and judge its quality is an important skill for students. Some schools have developed their own guidelines for effective electronic searching and posted them on their school Web sites (Georgetown-Visitation, 2006). Other teachers have developed these guidelines within the structure of the chemistry class itself.

Conclusion

"Teaching to the Standards" may be misinterpreted as a way of interfering with the teacher's prerogative to respond to the needs of the students. However, the national standards are prescriptive and not restrictive. They encourage teachers to develop ways, as supported by research, on how teaching and learning take place, to meet the needs of their students. The proper use of the standards includes a recognition that they deal with the theory and research results of learning and teaching. To use the standards effectively, time is needed to analyze one's teaching in light of this external set of standards, but this can be time well spent. Teaching is a powerful tool that can either help or hinder student learning. Don't students deserve the best efforts, reflection, evaluation, and revision of our teaching methods and materials that we can provide? Emphasis on the student as central to the process of learning is at the heart of the standards. If the opportunity to create the most effective learning environment for students is not central to our role of teachers, then what is?

Recommended Readings

Moog, R. S.; Farrell, J. J. *Chemistry: A Guided Inquiry;* John Wiley & Sons: Hoboken, NJ, 2006; Vol. 3. The POGIL process promotes student engagement and involvement in the chemistry classroom. This text provides the activities to be used by the students working in groups that support the POGIL process.

Zumdahl, S. S.; Zumdahl, S.; DeCoste, D. *World of Chemistry*. Boston, MA: Houghton Mifflin, 2006. This high school textbook is very helpful if a teacher needs to show that the standards are being met. In the teacher's edition of the textbook, there are chapter planning guides for each chapter. The standards that apply to each section of the chapter are cited in this planning guide.